Connecting the Smart-City Paradigm with a Sustainable Urban Infrastructure Systems Framework to Advance Equity in Communities

(P.I: S. Shekhar, A. Ramaswami, T. Tang, J. Marshall, V. Merwade)

Vision for the project

The overarching vision of our project is to link the smart city paradigm on sensor technologies and data sciences with an interdisciplinary integrated Social-Ecological-Infrastructural & Urban Systems (SEIUS) framework to advance WHEe outcomes in cities, with equity-first planning for physical infrastructure transitions.

Conduct interdisciplinary community-engaged research with

- 4 Local and regional governments: Minneapolis, St Paul, Tallahassee, Hennepin County
- Schools, teachers and students will be engaged in citizen science component helping reach many diverse neighborhoods within cities
- Multi-community Organizations: ICLEI-USA, National League of Cities, Metro-Lab, City/County Management Association, Hennepin University Partnership, and Metropolitan council of the twin cities.

Research Questions

Our project addresses two inter-connected overarching research questions:

RQ1: How can we better understand spatial equity (including inequality and fairness) in the context of 7 basic infrastructure provisioning and related wellbeing (*W*), health (*H*), environment (*E*) outcomes in cities (*WHE*)?

(Note: Equity, ⚖, is explored as the spatial distribution of the WHE outcomes and their correlates with SEIU parameters)

RQ2: Given the opportunity of transformative smart infrastructures on-horizon (e.g., smart electricity grid, autonomous vehicles) and their interactions with land use, buildings, solar PV deployment, urban farming and green infrastructure to manage climate risks, can smart spatial infrastructure planning in cities, initiated today, encompassing all 7 physical infrastructure sectors, advance all four WHEe outcomes?.

In particular, how does an equity first approach differ from conventional approaches that focus on "average" outcomes?

Research Objective

To address the key gaps in science, data and knowledge, we propose 3 broad research themes that are closely aligned with Education:

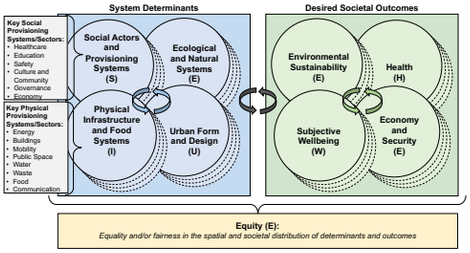
Theme 1: Develop comprehensive data sets on SEIS-EHW at intra-urban scales:
- **Cyber infrastructure** for diverse and disparate data sets
- **Novel citizen science, sensor and survey techniques** to characterize
  - air pollution
  - near-realtime flooding
  - subjective well-being (W)

Theme 2: Advance spatial data analysis to understand SEIU-*WHEe* relationships
- Advanced **spatial computing algorithms**
- Data and Discipline-inspired Hypotheses
- Equity (e) as spatial dispersion & correlation of *WHE*-SEIU

Theme 3: Model and visualize spatial smart city futures for Equity-First Plan
- **Multiple & connected spatial infrastructure futures** scenario modeling
- Scenario **Visualization**
- **Value of information** and policy-learning

Theme 4: Education and Workforce Development: Citizen science with middle & high-school students; Interdisciplinary Graduate Certificate; Professional education; Visualization for Policy Leadership;

Framework



Meta-principles for developing smart, sustainable, and healthy cities

- Ramaswami, Anu. "Unpacking the Urban Infrastructure Nexus with Environment, Health, Livability, Well-Being, and Equity." *One Earth* 2, no. 2 (2020): 120-124.
- Lara P. Clark, Samuel Tabory, Kangkang Tong, Joseph Servadio, Kelsey Kappler, Corey Kewei Xu, Abiola Lawal, Peter Wiringa, Len Kne, Richard Feiock, Julian D. Marshall, Armistead Russell, Anu Ramaswami. (In Revision, 2021). A data framework for assessing social inequality and inequity in multi-sector social, ecological, infrastructural and urban form (SEIU) systems: Focus on fine spatial scales. *Journal of Industrial Ecology*.

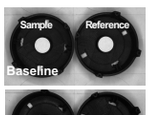
Lead: PI Ramaswami, Princeton

Current Results

Low-cost air pollution monitoring for Citizen Science

Paired sensors hanging from ceiling at 2 of 20 indoor locations.

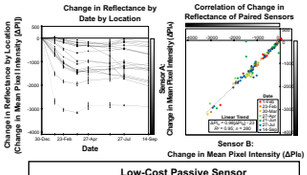
Passive Sample Collection

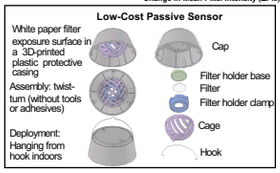


Digital Image Analysis

Low-cost passive sensors paired with a reference sensor

- Improved design of low-cost passive sensor (materials cost: <10 USD per sensor) and imaging approach.
- Tested precision and limits of detection of low-cost passive sensors in 20 indoor locations for 8 months. Results indicated:
  - High precision (for repeated measurements: r^2>0.97).
  - Ability to differentiate between higher vs. lower average air pollution exposures.
  - Limits of detection appropriate for longer-term (~1-3 months) monitoring indoors.
- Currently testing accuracy of low-cost passive sensors paired with reference sensors in 10 indoor locations.





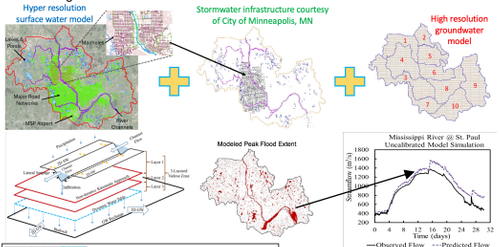
Lead: PI Marshall, UW

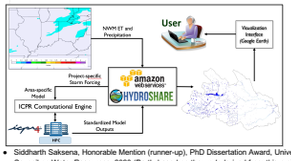
- Lara P Clark, et al. "Developing a Low-Cost Passive Method for Long-Term Average Levels of Light-Absorbing Carbon Air Pollution in Polluted Indoor Environments." *Sensors (Basel, Switzerland)* vol. 20,12 3417. 17 Jun. 2020, doi:10.3390/s20123417

Current Results (Continued)

Hyper resolution integrated flood modeling for urban environments

- Building the stormwater network at two resolutions





MSP model area: 340 mi²)

- Near-Realtime Flood Prediction using ICPR and NWM Forcing

S. Saksena, S. Dey, V. Merwade, and P.J. Singhofen. (2020) A Computationally Efficient and Physically Based Approach for Urban Flood Modeling Using a Flexible Spatiotemporal Structure. *Water Resources Research*, 56, e2019WR025769.

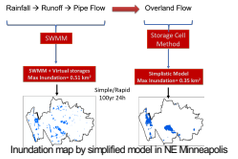
- Siddharth Saksena, Honorable Mention (runner-up), PhD Dissertation Award, Universities Council on Water Resources, 2020 (Partly based on the work derived from this project).

Lead: PI Merwade, Purdue

Simplified Fine Scale Flood Modelling to Understand Social Equity in Urban Street Flooding

To address both social equity and infrastructure aspects of urban pluvial flooding

- Understand where urban flooding is happening at finer scale through a citizen science survey project
- Develop a flood inundation model for rapid flood risk assessment in urban areas, informing neighborhood level vulnerability



Inundation map by simplified model in NE Minneapolis

342 survey responses collected in 2019 summer

Lead: PI Ramaswami, Princeton

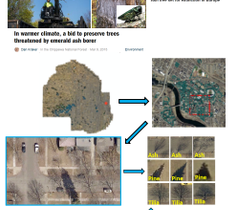
Revolutionizing Tree Management via Innovative Spatial Techniques

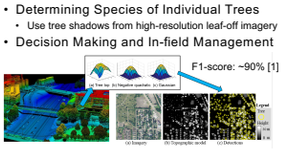
Theme 2: Advance spatial data analysis. **Task 2A:** Algorithms for spatial patterns

Trees near powerlines have caused
- Power blackouts
- Forest fires (e.g., deadly fires in California)

Invasive species have killed millions of ash trees, costing over $10-billion

- Problem: Lack of green infrastructure awareness
  - Location, type and wind resistance of trees relative to power line infrastructure.
- Manual collection of information is extraordinarily time-consuming and difficult
  - Blocked GPS signal under tree canopies
  - Hard to measure canopy sizes
- Proposed solution: Innovative Spatial Techniques
  - Geometric Profiling of Individual Trees
  - Determining Species of Individual Trees
    - Use tree shadows from high-resolution leaf-off imagery
  - Decision Making and In-field Management





- ~30 types of trees
- ~85% accuracy with three guesses

- Yiqun Xie, Han Bao, Shashi Shekhar, and Joseph Knight. "A TIMBER framework for mining urban tree inventories using remote sensing datasets." In *2018 IEEE International Conference on Data Mining (ICDM)*, pp. 1344-1349. IEEE, 2018.
- Yiqun Xie, Shashi Shekhar, Richard Feiock, and Joseph Knight. "Revolutionizing tree management via intelligent spatial techniques." In *Proceedings of the 27th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, pp. 71-74. 2019., **Best vision paper award.**
- Samantha Detor. Abigail Roh, Yiqun Xie, and Shashi Shekhar. "Analyzing Domain Knowledge for Big Data Analysis: A Case Study with Urban Tree Type Classification." In *International Conference on Big Data Analytics*, pp. 176-192. Springer, Cham, 2019.

Lead: PI Shekhar, UMN

Equity Analysis of Urban Food Systems through Urban Gardens

Work in Progress: Assess urban garden food production capacity.

Collaborators
- Anu Ramaswami, Dana Boyer, Peter Nixon Princeton
- J. Newell, D. Gounaridis, School for Env. and Sustainability (SEAS), University of Michigan.

Initial Approach
- Digitize urban garden from Google Earth imagery.
  - Developed a training dataset by walking the streets.
  - Served as initial dataset for AI based approach

Spatial computing approach
- Train distinct neural nets for each location to address spatial variability.
- Use high resolution spring aerial imagery to address occlusion and improve detection.
- Ground truth from initial approach are used for training.

Imagery Source: Hennepin County, Ramsey County, Fulton County

- Dana Boyer, Rachel Kosse, Graham Ambrose, Peter Nixon, Anu Ramaswami. (2020). A hybrid transect & remote sensing approach for mapping urban agriculture: informing food action plans & metrics. Landscape and Urban Planning - under review.
- Jayant Gupta, Yiqun Xie, and Shashi Shekhar. Towards Spatial Variability Aware Deep Neural Networks (SVANN): A Summary of Results. DeepSpatial2020. **Best Paper Award.**
- Yiqun Xie, Jayant Gupta, Yan Li, Shashi Shekhar, Transforming Smart Cities with Spatial Computing, IEEE International Smart Cities Conference (ISC2) 2018.

Lead: PI Ramaswami, Princeton

Challenges and Opportunities of Autonomous Vehicles to Urban Planning

- Illustrate planners' understanding of the potential opportunities and challenges that AVs bring to transit and planning implications for social equity.
- Achieve a better understanding of autonomous vehicles' impacts on different population groups such as low-income people, racial/ethnic minorities, immigrants, women, seniors, teenagers, and disabled people.
- Review and summarize current best practices for policies that address equity issues in autonomous vehicle deployment and determine the extent these policies are being implemented in the U.S. and in Minnesota.
- Provide policy recommendations that maximize the equity benefits and overcome the equity challenges of autonomous vehicles.

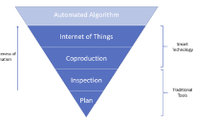
Research Impact: Wu, Xinyi, Frank Douma, Jason Cao, and Erika Shepard. 2020. Preparing transit in the advent of automated vehicles: A focus-group study in the Twin Cities. Findings November: 1-6.

Lead: Cao and Douma, UMN

Impact of E-governance technology on equity in public service delivery

Paper 1: Equity of Digital Governance Tools (311 systems)
- Information Communication Technologies (ICTs) (e.g., 311 systems provide an alternative tool for historically disadvantaged groups to communicate service needs with government.
- Minority groups are more likely to utilize smart technologies to submit service requests when in greater needs for public service.
- ICTs can potentially narrow or even close the equity gap in service delivery.

Paper 2: Administrative Behavior of Utilizing Various Tools
- Analyze and compare traditional and new tools during disaster recovery, including plan, inspection, ICTs and Internet of Things.
- New technologies capture wholistic information on single dimensions, but they cannot serve as substitute for traditional technologies due to lack of information on other dimensions, also fail to capture democratic values.



Paper 3: Estimating Individual Needs for Public Service.
- Depending on service requests data, combine with multiple dimensions on socio-economic characteristics, generate individual household level score of needs for power restoration services during disaster recovery.
- Solving the issue on low awareness of government communication platforms through directly assessing needs and proactively addressing the needs.

Research Impact: Publication in Public Administration Review. Invited to Public Administration Review Symposiums in Denmark (2019), Washington D.C. (2020), and London (2020). Presentations in Conferences of ASPA, APPAM, PMRC, SPSA.

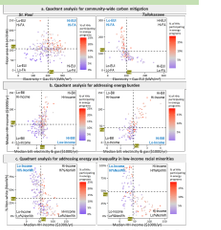
Xu, Corey Kewei, and Tian Tang 2020. Closing the Gap or Widening the Divide: The Impacts of Technology-Enabled Coproduction on Equity in Public Service Delivery. Public Administration Review

Data: Household level Tallahassee database – AMI energy consumption; Voter Registration; Property Appraiser; Energy Policy Participation; Renewable Energy Adoption.

Lead: PI Tang, FSU

Measuring social equity in urban energy use and interventions using fine-scale data

- Cities seek a nuanced understanding of intra-urban inequality in energy use, addressing both income and race, to inform more equitable investment in climate actions.
- Our study partners with cities and utilities to collect empirical data covering ~200,000 households in two cities.
- **Energy use intensity disparities by income and race** can be up to a factor of five larger than previously understood in US cities.
- **Spatial scale of data aggregation** impacts energy disparity ratios and Gini coefficient.
- **Quadrant analysis** evaluates energy-use inequality data to inform equitable investments in energy conservation and efficiency, guiding spatial prioritization for carbon mitigation and reducing social inequality.
- This study contributes to fundamental understandings of social inequality in energy use by race and income, the nature of energy inequality in the context of spatial scale in urban areas, and to demonstrate the applicable of the developed methods and metrics to cities.



Tong, K., Ramaswami, A., Xu, K., Feiock, R., Schmitz, P., & Ohlsen, M. (In Revision). Measuring social equity in urban energy use and interventions using fine-scale data. PNAS

Lead: PI Ramaswami, Princeton

Theme-3: Multi Infrastructure Modeling

- Ramaswami's group is implementing a framework to model urban energy transitions to electric heating and electric vehicles.
- explore transition patterns w.r.t urban form, typology, and circular economy.
- Collaboration with Kara Kocklemann in the SRN on SAV/SAEVs.
- Next steps: Collaboration with Merwade and Twine to include Heat and Storm Water Modeling

Lead: PI Ramaswami, Princeton

K-12 Citizen Science

Teacher workshops

- *Aug 2018* 2-day teacher workshop "Culturally Relevant Citizen Science Workshop"
- *March 2019* St. Paul, MN Professional development for St. Paul Public School Teachers, Citizen Science using *Survey123*

Teacher Training

- *July 2019* Sauk Rapids, MN ESRI professional development for k-12 teachers: 'Using survey123 and citizen science applications"
- *July 2019* I Minneapolis, MN ESRI professional development for k-12 teachers: 'Using survey123 and citizen science applications"
- *Oct 2019* St. Cloud MN GIS/LIS consortium: "Educators Day" training for teachers

Presentations

- *November 2019* Minneapolis Justice Page Middle School STEAM Night: S&CC team projects poster presentation
- *Oct 2019* St. Cloud MN GIS/LIS Consortium Presentation: Using Survey123 and ArcGIS online to explore citizen science as a democratic process in middle and High School Classrooms

J. Oesterle, B. Upadhyay, J.C. Brown, & M. Vernon. (2019). Citizen Science: A path to Democratic and Sociopolitically Conscious Science. In P. P. Trifonas (ed.), Handbook of Theory and Research in Cultural Studies and Education, Springer International Handbooks of Education (pp.1-30). Springer Publisher. https://doi.org/10.1007/978-3-030-01426-1_28-1

Lead: Upadhyay, UMN

Community Engagement

Citizen Science with Schools For Neighborhood Infrastructure & Wellbeing Assessments

- **Innovation**: Engaging Middle-High Schoolers in neighborhood exploration, data gathering , online reporting/mapping and discourse on equity (Project Lead: Upadhyay, UMN).

- **Innovation**: First attempt to measure both cognitive WB, emotional WB and life purpose, in diverse neighborhoods along with satisfaction with soft/hard infrastructure at the neighborhood level. (Task lead: PI Ramaswami, Princeton)
  - Survey at Minnesota 2019 State Fair ~350 responses collected in a week

Researchers survey fairgoers about street flooding

City and County Partners:
- Brette Hjelle & Kathleen Mayell, Minneapolis
- Matt Larson, St. Paul
- Michael Ohlsen, Tallahassee
- Alisa Salewski, Hennepin County

Link: https://survey123.arcgis.com/share/c435259e4f44442db3eacdf8908b6362

Schools Partners:
- Charlene Ellingson, Minneapolis Public Schools
- Betsy Stretch, Minneapolis Public Schools
- Sophie Sigel, St. Louis Park High School, MN

Multi-Community Organizations/Other:
- Cooper Martin, National League of Cities
- Angie Fyfie, ICLEI-USA
- Tad McGalliard, Intl. City/County Management Association
- Ben Levine, MetroLab Network
- Scott Vargo, Hennepin University Partnership
- Mauricio Leon, Senior Researcher, Metropolitan Council of the Twin Cities

NSF Sustainable Research Network:
- Sustainable Health Cities (SHC)